

# **Optical Properties Of Mineral Particles And Their Effect On Remote-Sensing Reflectance In Coastal Waters**

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## **LONG-TERM GOAL**

My long-term goal is to develop the base of knowledge necessary to:

- (i) understand the magnitudes and variability of the optical properties of the ocean;
- (ii) predict the inherent and apparent optical properties of the ocean, including remote-sensing reflectance, given the types and concentration of suspended particles;
- (iii) retrieve the inherent optical properties and concentration of optically significant constituents of sea water from reflectance measurements.

## **OBJECTIVES**

Suspended mineral particles are a major optical component of coastal ocean but very little work has been done to characterize the absorption and scattering properties of these particles. My objectives for this past year were to:

- (i) develop an approach to modeling the inherent optical properties of a water body as a function of the detailed composition of particulate assemblage;
- (ii) develop inverse models for estimating the inherent optical properties from underwater radiometric measurements and the apparent optical properties;
- (iii) measure the optical properties within a marine environment that exhibits dramatic variations in the optical water type, from the mineral-dominated to phytoplankton-dominated type.

## **APPROACH**

My database of single-particle optical properties described in past reporting periods includes 18 planktonic components, organic detritus, mineral particles, and air bubbles (Stramski et al., 1998). There is the need to further expand and improve the database. For example, because of the lack of data the present characterization of minerals and detritus is based on the overly simplified approximations to the size distribution and refractive index of these components. Nevertheless, the present database provides the foundation for modeling the inherent optical properties (IOPs) as a function of the detailed composition of suspended particulate matter. In this reporting period, I developed an approach based on the database, which allows us to examine the IOPs as the composition of particulate matter is varied in a controlled manner (Stramski et al., submitted). The variations in the composition of particles are

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effected by changing the concentration of 21 individual components. As a result, the simulated water body is described in terms of the component particle size distributions. Having determined the component concentrations, the corresponding component IOPs are readily calculated using the single-particle optical properties from the database.

The approach to develop inverse models for estimating the IOPs within the surface layer is based on extensive numerical simulations of radiative transfer in the upper ocean. Two types of models were addressed. The first model was developed to allow the retrieval of absorption ( $a$ ) and backscattering ( $b_b$ ) coefficients in the blue-green spectral region from irradiance and radiance data collected from ships or autonomous platforms (Stramska et al., submitted). The model requires the measurement of upwelling radiance,  $L_u$ , and downwelling and upwelling irradiances,  $E_d$  and  $E_u$ , at as few as 2 depths but no knowledge of surface boundary conditions (sun elevation, sea and sky state) is needed. The second model was developed to estimate  $a$ ,  $b_b$ , and total scattering coefficient ( $b$ ) from two apparent optical properties (AOPs), irradiance reflectance just beneath the sea surface,  $R(0^-)$ , and the attenuation coefficient for downwelling irradiance,  $\langle K_d \rangle_1$ , within the first attenuation depth (Loisel and Stramski, submitted). This model accounts for the presence of Raman scattering and it is suited to remote sensing applications because both AOPs involved in the model can be derived from remotely-sensed water-leaving radiances.

The optical measurements in mineral-dominated waters were carried out in Kongsfjord (northwestern Spitsbergen) during the cruise on *R/V Oceania* in July 1999. This cruise was part of the research program of the Polish Academy of Sciences, and my participation in the cruise was supported by NASA. In situ measurements included the spectral downwelling irradiance and upwelling radiance (SPMR, Satlantic), beam attenuation at 488 nm and 660 nm (C-Star, WetLabs), backscattering at six wavelengths (Hydroscat-6, HobiLabs), absorption/backscattering at 442 and 510 nm (a-beta, HobiLabs), chlorophyll fluorescence (WetStar, WetLabs), temperature and salinity (CTD, SeaBird). In addition, water samples for analysis of particulate and soluble absorption spectra, chlorophyll concentration, particulate organic carbon, and mineralogical composition were taken.

## **WORK COMPLETED**

The single-particle optical property database was presented at the Ocean Optics XIV Conference in Hawaii in November 1998 (Stramski et al., 1998). The paper describing the modeling of IOPs based on the database was completed and submitted for publication (Stramski et al., submitted).

An extensive set of radiative transfer simulations for developing the two inverse models that allow the retrieval of IOPs from radiometric data and AOPs were completed. The papers describing these models were completed and submitted for publication (Stramska et al., submitted; Loisel and Stramski, submitted).

Cruise preparations including integration of two a-beta instruments with our multi-sensor datalogger system were completed. During the Kongsfjord phase of the Arctic cruise two instruments (SPMR and Hydroscat-6) failed but still we were able to collect a valuable set of data. Data processing and analyses of water samples are in progress.

In addition, one paper resulting from work described in the past reporting periods was published recently (Stramski, 1999).

## RESULTS

The simulations of our IOP model based on the database show how the separation and understanding of the effects of various optically significant particulate components is achieved (Stramski et al., submitted). Figure 1 shows selected results from this work, which may represent considerable realism in simulation of moderately turbid, near surface water under moderate winds. This example simulation emphasizes a unique role the mineral particles can play in determining the optical properties of a water body. While minerals are the least important particulate component for the absorption coefficient, they become by far the most important backscattering component in this simulation.

The inverse model described in Stramska et al. (submitted) shows the feasibility of retrieving the  $a$  and  $b_b$  coefficients in the blue-green spectral region with reasonable accuracy (generally much less than 10%) just from measurements of  $E_d$ ,  $E_u$ , and  $L_u$  at as few as 2 depths. We developed a relatively simple algorithm which accounts for variations in the angular distribution of light, and therefore no information about the sun elevation, sky, and sea state is needed to run the model. The model retrievals were compared to absorption data measured with ac-9 and laboratory spectrophotometers, and backscattering data measured with Hydrosat-6. The retrievals are as consistent with measured data as allowed by the accuracy of measurements.

Our second inverse model (Loisel and Stramski, submitted) is useful to satellite applications because the model input,  $R(0^-)$  and  $\langle K_d \rangle_1$ , can be retrieved from ocean color remote sensing. This model provides the best estimation for  $a$  and  $b_b$  in the blue and green spectral regions where the errors of a few percent to  $< 10\%$  are expected over a broad range of optical water types. While the estimation of  $a$  and  $b_b$  shows relatively little sensitivity to changes in the particle scattering phase function, the retrieval of the total scattering coefficient is greatly affected by such changes (Fig. 2). This result indicates a need to further examine the effects of scattering phase function on inverse models, especially for coastal waters where varying proportions of mineral and organic particles are expected to induce significant variations in phase function.

## IMPACT/APPLICATIONS

The major impact of this project is to fill the gap in our understanding of how the mineral particles suspended in sea water absorb and scatter light, and how these particles affect the apparent optical properties of the ocean including remote-sensing reflectance. Through the development of a quantitative characterization of the optical properties of mineral particles, this project will lead to better understanding of the roles played by various types of sea water components, which is a prerequisite to advancing numerous applications associated with optical measurements.

Our single-particle optical database is the most extensive ever assembled and it facilitates a new approach to optical modeling with considerable realism and unprecedented detail. The traditional approaches based on chlorophyll concentration alone or just a few components such as phytoplankton, detritus, and CDOM, are unable to explain or predict the substantial optical variability actually observed in the field. Our reductionistic approach will have a major impact on the study of ocean optics because it will lead to better understanding of the optical variability induced by various types of hydrosols present within a water body. This is a powerful research tool which enables the study of IOPs as the detailed composition of particulate assemblage consisting of many components is varied in a controlled manner as desired. In addition, the combination of this approach with radiative transfer

modeling provides an ideal means of separating and understanding the effects of various components on light fields within and leaving water bodies (Mobley and Stramski 1997). An important application of this modeling is in the area of ocean color remote sensing.

The existing inverse models for deriving IOPs have limited practical value because a set of input variables needed to run those models requires a special design of experiment, for example measurements at different sun angles throughout the day or the detailed vertical profiles. The models we developed address these deficiencies. The first model is applicable to in-water measurements from ships and autonomous platforms and it requires the determinations of  $E_d$ ,  $E_u$ , and  $L_u$  at as few as 2 depths. No information about the sun position, sky, and sea state is needed. The second model is applicable to both in-situ measurements and remote sensing, and it requires the determinations of the two AOPs,  $R(0^\circ)$  and  $\langle K_d \rangle_1$ , and the sun zenith angle. In contrast to other remote sensing models, our model does not require any assumption about the spectral behavior of IOPs.

## TRANSITIONS

Parts of my particle database were made available to several researchers and the entire database was made available to C. Mobley to carry out a collaborative study described in the past reports.

## RELATED PROJECTS

My participation in the Arctic cruise was supported by NASA. The cruise was sponsored by the Polish Academy of Sciences. The goal of my NASA project (in collaboration with Dr. M. Stramska from USC) is to make measurements in the Greenland and Norwegian Seas in support of MODIS ocean color validation program. The study of mineral-rich waters of Spitsbergen is a component of this project and was not planned in the NASA project.

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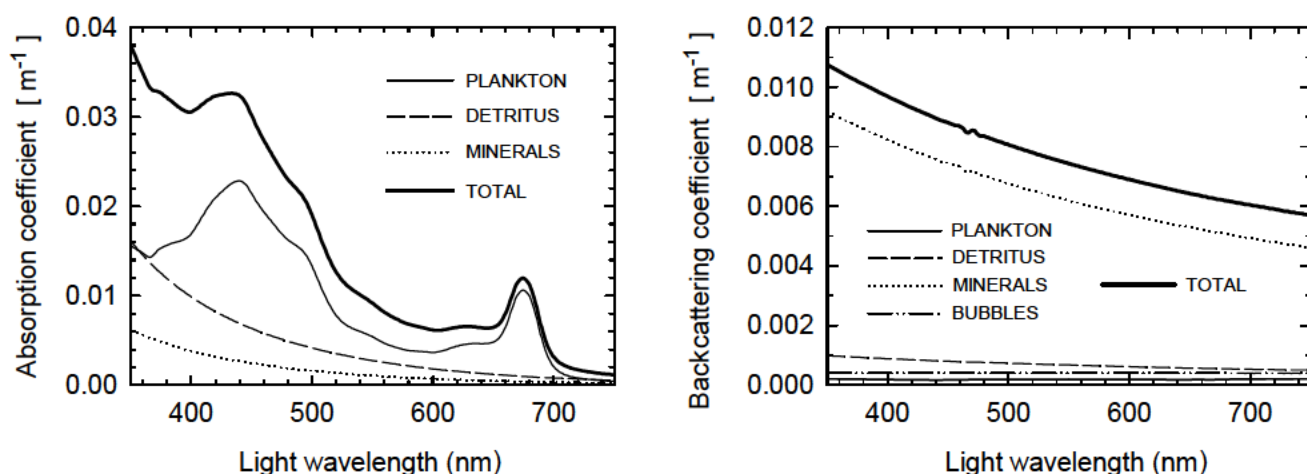


Fig. 1. The absorption (left-hand panel) and backscattering (right-hand panel) coefficients as obtained from the simulation of the IOP model based on the single-particle optical property database (Stramski et al., submitted). The eighteen planktonic components altogether make the dominant contribution to the absorption coefficient but are negligible for backscattering. The mineral particles are by far the most important backscattering component but their contribution to absorption is relatively small.

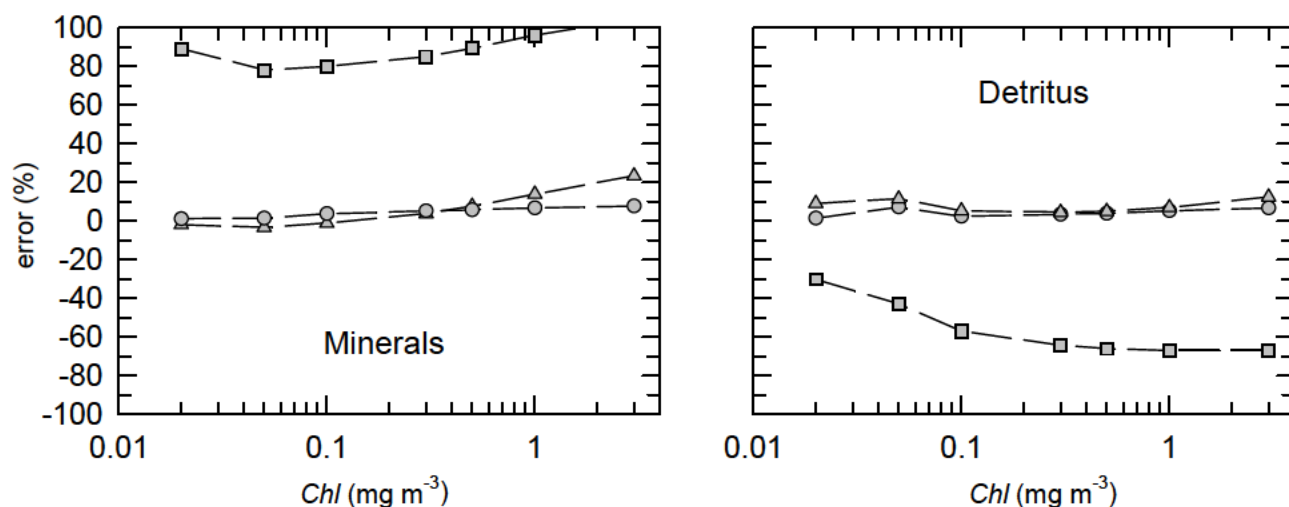


Fig. 2. The effect of the mineral (left-hand panel) and organic detritus (right-hand panel) scattering phase functions on the estimation of the  $a$  (circles),  $b$  (squares), and  $b_b$  (triangles) coefficients from our inverse model (Loisel and Stramski, submitted). The percent errors in the estimated values are plotted as a function of chlorophyll  $a$  concentration. The model was developed using the Petzold average particle phase function, which differs significantly from mineral and detritus phase functions.